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PREPARATION OF OCEAN MODEL FORCING PARAMETERS FROM FNWC ATMOSPHERIC ANALYSIS AND MODEL PREDICTIONS

by

Patrick C. Gallacher

December 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A software system is described which produces atmospheric fields on the time scale necessary to force the Garwood (1977) mixed layer model. The fields required are the surface wind speed, solar radiation and total heat flux. These fields are obtained from the NORPAX data center and from FNWC. The winds are available at 6 hour intervals and the heat fluxes at 12 hour intervals. The software system edits, reformats and interpolates the fields to 1 hour intervals. The system also provides the capability to extract specific grid points for any time interval desired.

LIST OF FIGURES

A

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1. Introduction

The problem we are addressing is the development of thermodynamic ocean models which will simulate the horizontal variability of vertical mixing in the upper ocean. These models will be capable of simulating the upper ocean response to local atmospheric forcing on synoptic to seasonal time scales. The spatial response of the models will be consistent with resolution of the atmospheric fields used as forcing; thus the atmospheric fields should accurately represent the mesoscale to large scale variability of the atmosphere. The fields which are needed to force the models include the solar radiation, the total heat flux and the wind speed at the ocean surface. The atmospheric prediction models and the analyses of atmospheric observations used by Fleet Numerical Weather Central (FNWC) to produce operational weather forecasts can provide the atmospheric forcing for these ocean models.

This report describes a software system which has been designed to produce the time series of atmospheric fields needed to drive a one-dimensional, turbulence closure, thermodynamic ocean model (Garwood, 1977a), from the FNWC analysis of the surface marine wind field, and the FNWC predictions of solar radiation, and total heat flux at the ocean surface (FNWC, 1974). Steve Pazan, the North Pacific Experiment (NORPAX) data manager, has provided us with the FNWC fields for the Anomaly Dynamics Study (ADS) region (30-50N, 140E-130W), Fig. 1. This data set is on a 11 x 41 grid for the years 1976 and 1977 (Anomaly Dynamics Study, 1978). Since March 1978, we have been receiving the fields directly from FNWC on the 63 x 63 polar stereographic Northern Hemispheric grid, Fig. 2. The results discussed in this report have been obtained using the ADS data set; however, the software system is directly applicable to the FNWC data set.

The diurnal heating of the upper ocean and its coupling to the synoptic scale wind field have been shown to be important in predicting the seasonal

and annual cycles in the upper ocean (Garwood, 1977b) due to the nonlinearity of the ocean response to the atmospheric forcing. The mixed layer model must be supplied with atmospheric forcing at least every 3 hours to properly resolve the ocean response to the diurnal signal. The sea level (10 m) winds, from the FNWC analyses, are saved at 6 hour intervals. Instantaneous values of the surface heat fluxes are recorded every 12 hours (every 6 hours since March 1978). These fields are permanently archived on magnetic tape and are available to the scientific community. The mission of FNWC is to provide environmental support for fleet units; hence, the archiving of fields for later research has not been a primary consideration. As a result all the FNWC fields were not archived for every 6 or 12 hour interval. In addition, some archived fields were duplicated when test runs of the models or analyses were inadvertently recorded. The number of missing or duplicate fields is normally less than 10% of the total for any month. The incidence of missing or duplicate fields is becoming less frequent as the interest in using the archived fields increases. Nevertheless, part of the function of our data management system must be to locate and correct missing and duplicate fields. Additionally, it must be noted that while the surface fluxes are of primary importance to ocean modeling, they are of secondary importance in atmospheric models. Thus the FNWC fields must be carefully screened for any bias or systematic error which, while not important to the atmospheric model in operational integrations, could overwhelm the ocean model during longer term integrations.

2. System Description

The software system, which converts the FNWC atmospheric boundary layer fields into the forcing required for the Garwood mixed layer model, consists of nine programs divided into three quasi-independent subsystems, Fig. 3. This approach provides natural breaks in the data management and gives the

system greater flexibility by limiting the amount of computer time required for any one run. This method also allows the system to be used with alternative atmospheric data sets and to accomplish a variety of functions which can easily be altered to accommodate the different data sets.

The first subsystem, REFORMAT, reformats, edits and sorts the FNWC fields, Fig. 3a. The resulting data set is compatible with the IBM 360/67 computer system at the Naval Postgraduate School, and can be read more than an order of magnitude faster than the original. The next subsystem, RETRIEVE, retrieves any desired subset in space and time of the data set generated by REFORMAT, and interpolates values for the missing fields which were flagged by REFORMAT, Fig. 3b. The final subsystem, INTERPOLATE, interpolates the FNWC fields to the time interval required for the model, Fig. 3a. Some of the fields require specialized interpolation schemes due to the distinctive character of the fields.

Each subsystem will be discussed in detail in the following sections. All the programs in this system were written in FORTRAN IV with the exception of the sorting program, which is an IBM utility program. All the data files are written in binary format, which yields a considerable savings in file space and processing time. Each data file contains a header record, which specifies the space and time domain of the data, followed by the data records.

2a. Reformat Subsystem

The REFORMAT subsystem consists of three programs that transform the FNWC fields into the format used by our software system. The first of these programs RFMT, unpacks the FNWC or ADS data tapes, and converts the data fields to 4-byte real variables with the proper physical units. The FNWC fields are archived as 4 character octal variables to conserve space on the data tapes. The second program, EDIT, tests the RFMT generated data file for missing and

duplicate records. Each data record contains an entire grid of data points for one surface parameter at a given time. Duplicate records are dropped from the file and missing records flagged by inserting a grid of 999.9 values for the missing record. The data file generated by the EDIT program contains a record for each surface parameter for every time interval. The 999.9 grids which have been inserted for missing records can be replaced with reasonable values or deleted from the file later in the processing. This arrangement allows considerable flexibility in handling the data. The final program in the subsystem, SORT, arranges the data records in chronological order. The data files, which results from the REFORMAT subsystem, contains a data record for every FNWC field at each time interval. This data file can be read at least 20 times faster than the original FNWC or ADS tapes.

2b. Retrieve Subsystem

The RETRIEVE subsystem consists of two programs which can extract any subset of the files generated by the REFORMAT subsystem and replace the missing (999.9) records with useable data values. The first program, RTRV, extracts the desired data as specified by a control card. The control card designates the initial and final latitudes and longitudes, the date and time of the first record and the number of records to be extracted. The requested subset is retrieved and a data file is created for each of the FNWC surface parameters. The second program, CRCT, searches the files generated by RTRV and replaces the missing (999.9) fields with data values derived by linear interpolation.

The RETRIEVE subsystem generates four data files;one each for the zonal surface wind component, the meridional surface wind component, the surface solar radiation and the total heat flux at the surface. Each data file contains a complete time series for a FNWC field. These can now be interpolated to the time step of the ocean model.

2c. Interpolation Subsystem

The INTERPOLATION subsystem is composed of four programs which interpolate the FNWC fields to 1 hour intervals for the Garwood mixed layer model. The characteristics and archiving frequency of the individual FNWC fields must be considered in choosing an interpolation scheme for each field. For example, the wind fields can be interpolated using a straightforward cubic spline method; however, the interpolation of the solar radiation requires a more complicated procedure. The cubic spline routines are taken from the International Mathematics and Statistics Library (IMSL, 1979). The interpolation to hourly intervals is a two step process. In the first step the coefficients of the cubic spline are calculated at each knot, which is defined as an interpolated point. In the second step, the coefficients are used to evaluate the cubic spline between the knots.

The wind components are interpolated using the program FRCFI, which serially interpolates each grid point and outputs a time series of hourly records; each record containing all the grid points for that hour. After FRCFI is run for both wind components, the program, WNDSP, is used to calculate the wind speed at each grid point from the wind components. A typical wind speed profile is shown in Fig. 4. The wind speeds computed from the original 6 hour wind components are marked with a vertical bar.

The program, A11I, is used to interpolate the solar radiation to 1 hour intervals. The solar radiation has a semi-diurnal periodicity and only one instantaneous value each 12 hours, at 00GMT and 12GMT; thus a simple interpolation scheme is not feasible. Instead we make use of Malankovich's formula to estimate hourly values of the solar radiation. Malankovich's formula is given as

$$\frac{I_i}{I_n} = \frac{\sin\alpha_i}{\sin\alpha_n}\; q^{\left(\frac{1}{\sin\alpha_i} - \frac{1}{\sin\alpha_n}\right)} \quad ;$$

where I_i = surface solar radiation of the i-th hour from local noon,

I_n = surface solar radiation at local noon,

q = water vapor absorptance for the atmosphere which is taken as 0.7,

$\alpha_i = \sin\phi \sin\delta + \cos\phi \cos\delta \cosh_i$,

ϕ = latitude,

δ = solar declination,

h_i = hour angle for the i-th hour (15^o/hour).

Values of $\frac{I_i}{I_n}$ for $\delta = 23^o$ (spring equinox), $\delta = 0^o$ (summer solstice) and $\delta = -23^o$ (vernal equinox) at 40N are shown in Fig. 5. Malankovich's formula is used to calculate the solar radiation each hour from one hour after sunrise to one hour before sunset based on the 12 hour FNWC value which falls closest to local solar noon. This method of calculating the hourly solar radiation assumes that the atmospheric water vapor and cloudiness are constant during the hours of daylight. Thus high frequency variability in the instantaneous measurements of the solar flux due to clouds and water vapor are not included. Rather the assumption is that the significant time scales for heating the ocean are related to the synoptic storm systems and the diurnal cycle of heating and cooling. Accumulation of these synoptic and diurnal scale heat fluxes result in the synoptic to seasonal scale variability in the heat content of the upper ocean through vertical mixing. Fig. 4 is a typical example of the interpolated solar radiation, with the FNWC values shown as "x". The program, A18I, interpolates the 12 hour FNWC fields of the total heat flux to hourly intervals. This interpolation is a three step process because the solar flux must be handled separately. First, the original 12 hour solar radiation values are subtracted from the corresponding total heat fluxes to form a residual heat flux. The residual heat flux includes the sensible, latent and long wave heat

fluxes; each of which is a smoothly varying function with synoptic scale variability. Therefore we can interpolate hourly values of the residual heat flux from the 12 hour values. The method employed is identical to that used for the wind components. The last step in the procedure is to add the hourly solar radiation fields, created by A11I, to the hourly residual heat fluxes to form hourly total heat flux fields. A typical result is shown in Fig. 4.

3. Conclusions

This system accomplishes the task of manipulating the FNWC atmospheric boundary layer fields into time series of forcing for the Garwood mixed layer model. The divisions of the system into the particular subsystems and programs discussed above facilitates data control during both system testing and production. It also allows the system to be easily restructured to accommodate different data sets, or different methods of data manipulation. The compartmentalization of the system simplifies its use by other groups; few if any changes would have to be made and these would involve a minimum number of programs or subsystems. A brief documentation of the programs, and auxillary programs and subroutines is given in the Appendixes.

Preliminary tests (Elsberry, Gallacher and Garwood, 1979) indicate that the system accurately handles the FNWC fields and prepares useable forcing for the Garwood model. Testing is being continued to determine the feasibility of long term ocean prediction using the FNWC fields. We need to consider both the accuracy of the low frequency components and the lack of high frequency (>2 cpd) resolution in the FNWC fields. The surface heat flux fields are of primary importance to ocean modeling; however, they produce only second order effects in the atmospheric models. Thus a bias could exist in the surface heat fluxes that may not impair the atmospheric forecasts but which could result in systematic errors in long term ocean simulations. Additionally, we know that during the

spring transition and the fall deepening of the ocean mixed layer, the phase difference between the wind forcing and the surface heat fluxes can critically affect the ocean response on synoptic time scales (Elsberry and Garwood, 1978). It is not known if the high frequency variability is also important for seasonal and annual simulations. The answer to this has serious implications since the FNWC fields can not resolve diurnal and higher frequency variability. Also the peak values tend to be reduced by the objective analysis schemes which are used to produce the wind speed and surface heat flux fields. Several tests and experiments are being conducted to resolve these questions.

As we have discussed, the software system can handle ADS or FNWC generated surface fields. The system can be adapted, with minimum modifications, to handle satellite data or surface data from ocean experiments such as MILE, FRONTS, and STREX. Thus we can look at the results from a variety of sources on several space and time scales.

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The author would like to thank Warren White and Steven Pazan of NORPAX for providing the ocean data and the ADS surface fields, and LCDR Loveless of FNWC for providing the FNWC surface fields. Russ Elsberry and Bill Garwood of the Naval Postgraduate School have provided guidance and suggestions. The computing was done at the Church Computer Center at the Naval Postgraduate School. Michele Nunez typed the manuscript. This research has been supported by the Naval Ocean Research and Development Activity (Code 320) under N6B46279WR90029.

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Appendix A

PROGRAM: RFMT

PURPOSE: To reformat the FNWC or ADS data tapes, creating a new data set which is compatible with the IBM 360/67 computer system at the Naval Postgraduate School.

INPUT: ADS or FNWC data tape.

OUTPUT: A data file in binary format with all data values in physical units and unnecessary header information deleted.

PROCESS: The header record and data records are read from the ADS or FNWCS tapes. The scale factor given in the header record is used to convert the data elements from 4 character octal constants to real *4 variables. A shortened version of the header record is output followed by the data records. All the output records are binary (i.e. written using FORTRAN unformatted writes statements).

Appendix B

PROGRAM: EDIT

PURPOSE: To remove duplicate records and fill in missing records in the data file.

INPUT: Data file generated by RFMT.

OUTPUT: A binary data file with no duplicate fields and a data record for every time interval and a printed summary of the actions taken by the program.

PROCESS: The input file is scanned for duplicate date-time fields and for missing date-time groups. A duplicate date-time group is defined, in the program, as a date-time group which is less than the date-time group which is expected for the data record which the program has read. When a duplicate record is located the catalog number and date-time group are printed on the summary sheet and the data record is not written to the output file. A missing date-time group is located when the date-time group of the data record is greater than the date-time group expected by the program. When a missing record is located, the missing date-time group and catalog number are printed on the summary sheet and a data record filled with 999.9 values is written to the output file.

Appendix C

PROGRAM: SORT

PURPOSE: To put the data file generated by EDIT in chronological order.

INPUT: Data file generated by EDIT.

OUTPUT: A data file in chronological order.

PROCESS: The input file is sorted into ascending order on the date-time group by the IBM utility sort program.

Appendix D

PROGRAM: RTRV

PURPOSE: To retrieve from the complete data set of forcing functions a time series for each forcing function at the grid points specified on the control card. The time series starts on the day specified and contains the number of days specified by the programmer.

INPUT:
1. ADS forcing tape which contains the wind velocity components at 6 hour intervals, the total heat flux, the solar radiation, the evaporative heat flux, the cumulative precipitation and the total cloud cover every 12 hours.
2. Control card containing the initial and final latitude and longitude of the grid point(s) to be retrieved, the date-time of the bėginning of the time series and the number of days to be extracted.

OUTPUT:
1. Time series of the solar radiation (A11) for the grid point(s), starting time and number of days specified in the control card.
2. Same as (1) but for the total heat flux (A18)
3. Same as (1) but for the E-W wind component (A29)
4. Same as (1) but for the N-S wind component (A30)

PROCESS: The program reads the control card and translates the latitude and longitude into array indices. The beginning date-time is translated into Julian date format and an ending date-time is computed using the number of days to be retrieved. The input file is searched and all records with catalog numbers A11, A18, A29, A30 which fall between the starting and stopping time are extracted and placed in the output files by catalog number.

Appendix E

PROGRAM: CRCT

PURPOSE: To replace any missing fields in the files created by RTRV.

INPUT: Any one of the files generated by RTRV.

OUTPUT: A new file which contains a useable value for every date-time.

PROCESS: The input file is scanned for records containing a data value of 999.0. When a record containing this value is found the 999.0 value is replaced with a value derived by linear interpolation using the two nearest values in time. The 999.0 values were inserted for all fields which were missing in the original data tapes by the program EDITA. The program outputs a new time series which consists of all the data records from the input time series with the 999.0 values replaced with interpolated values. Note: This program must be run for each file generated by RTRV1D.

Appendix F

PROGRAM: A11I

PURPOSE: To interpolate the values of solar radiation to 1 hour time intervals.

INPUT: Time series of solar radiation (A11) generated by CRCT.

OUTPUT: Time series of solar radiation at 1 hour intervals.

PROCESS: One day of data points are read from the input file, sunrise and sunset are computed for that day. The data value which is closest to local noon is located. Data values are then computed for every hour between sunrise and sunset using Malankovich's formula, which states that

$$I(h) = \frac{\sin\alpha_h}{\sin\alpha_n} \quad I(n) \quad q^{\left(\frac{1}{\sin\alpha_h} - \frac{1}{\sin\alpha_n}\right)}$$

where $\sin\alpha_h = \sin\phi \sin\delta + \cos\phi \cos\delta \cos h$

ϕ = latitude

δ = solar declination

h = hour angle = (TIME-NOON) $*15^{\circ}$/hr

$q = 0.7$

$I(n)$ = data value nearest noon.

The interpolated values are then written to a file with the values for night time hours set to zero.

Appendix G

PROGRAM: A18I

PURPOSE: To interpolate the values of total heat flux to 1 hour intervals.

INPUT:
1. Time series of total heat flux (A18) generated by CRCT.
2. Time series of solar radiation (A11) generated by CRCT.
3. Time series of solar radiation (A11) generated by A11I.

OUTPUT: Time series of the total heat flux at 1 hour intervals.

PROCESS: The 12 hour interval values of the solar radiation are subtracted from the 12 hour values of the total heat flux to obtain the residual heat flux. This residual heat flux is interpolated to 1 hour time intervals using cubic splines (the IMSL cubic spline routines are used). The values of solar radiation at 1 hour intervals are now added to the interpolated residual heat flux to obtain the total heat flux at 1 hour intervals.

Appendix H

PROGRAM: FRCFI

PURPOSE: To interpolate any field which does not require special handling to a 1 hour time interval.

INPUT: Time series of field to be interpolated (in our case this is one of the wind components).

OUTPUT: Time series of forcing at 1 hour time intervals.

PROCESS: The input time series is read and interpolated to 1 hour intervals using the IMSL cubic spline routines. The results are output to a new file.

Appendix I

PROGRAM: WNDS

PURPOSE: To form a wind speed (A27) from the E-W and N-S wind components.

INPUT:
1. The N-S wind components (A30) at 1 hour intervals.
2. The E-W wind components (A29) at 1 hour intervals.

OUTPUT: The wind speed at 1 hour time intervals.

PROCESS: The wind speed is computed from the wind components (i.e. $W = (W_x^2 + W_y^2)^{1/2}$). The results are then output to a new file.

Appendix J

PROGRAM: TSERS

PURPOSE: To plot time series of the forcing functions used by the model.

INPUT:
1. The solar radiation (A11) time series at 1 hour intervals.
2. The total heat flux (A18) time series at 1 hour intervals.
3. The wind speed (A27) time series at 1 hour intervals.
4. A control card giving the min and max values of the x and y variables for each plot.

OUTPUT: A versatec plot of the solar radiation, total heat flux and wind speed as functions of time.

PROCESS: The program inputs the control card and time series and uses versatec plot calls to build a complete plot with axes, labels and titles.

Appendix K

SUBROUTINE: LOCADS

PURPOSE: To convert from latitude(s) and longitude(s) to array indices.

INPUT:
ALATC1 - starting latitude of the grid point(s) of interest.
ALONC1 - starting longitude of the grid point(s) of interest.
ALATC2 - ending latitude of the grid points of interest.
ALONC2 - ending longitude of the grid points of interest.
DELAT - displacement in degrees latitude between desired grid points.
DELON - displacement in degrees longitude between desired grid points.

OUTPUT:
ILAT1 - array index of first grid point for latitude index.
ILON1 - array index of first grid point for longitude index.
ILAT2 - array index of last grid point for latitude index.
ILON2 - array index of last grid point for longitude index.
LATD - increment between desired grid points for latitude index.
LOND - increment between desired grid points for longitude index.

PROCESS: The subroutine computes the starting and ending values of the array indices and the increment for the indices based on the latitudes, longitudes and displacements passed to the subroutine. For the one dimensional case (only one grid point desired) ALATC1 and ALONC1 are set to the latitude and longitude of the grid point. ALATC2 = ALONC2 = DELAT = DELON = 0 (or blank). In this case the array indices of the grid point are returned from the subroutine in ILAT1 and ILON1. For the two dimensional case, ALATC1 and ALONC1 are the latitude and longitude of the lower left hand corner (point furthest to the south and west) of the set of grid points desired; ALATC2 and ALONC2 are the latitude and longitude of the upper right hand corner of the set of grid points; DELAT is the latitude displacement between desired grid points and DELON is the longitude displacement between desired grid points. If DELAT = DELON = 0.0, the subroutine sets ILATD and ILOND to one so that no grid points are skipped. If DELAT and DELON were set to twice the spacing between the original grid points, ILATD and ILOND are set to 2 so that every other grid point will be used by the calling program.

Appendix L

FUNCTION: JULIAN

PURPOSE: To convert from a calendar date-time to a Julian date-time.

INPUT: Calendar date-time in the form YYMMDDTT
where YY = year - 1900 i.e. 78 = 1978
MM = month
DD = day
TT = time in hours i.e. 1200 = 12

OUTPUT: Julian date-time group in the form YYDDDTT
where YY is the same as above
DDD is the day of the year i.e. Jan 10 = 010
TT is the same as above.

PROCESS: The function calculates the Julian date-time group which corresponds to the calendar date-time group sent to the function. Leap years are taken into account.

Appendix M

FUNCTION: ICLNDR

PURPOSE: To convert from a Julian group in the form YYDDDTT (see JULIAN for definitions).

OUTPUT: Calendar date-time group in the form YYMMDDTT (see JULIAN for definitions).

PROCESS: The function calculates the calendar date-time group which corresponds to the Julian date-time group sent to the function.

Appendix N

SUBROUTINE: SUN

PURPOSE: To calculate sunrise in GMT and the number of hours of daylight for any latitude, longitude and day of the year.

INPUT:
ALAT - latitude of grid point
ALON - longitude of grid point
DAYNO - day of the year.

OUTPUT:
DEC - solar declination
ALATR - latitude of point in radians
SUNR - time of sunrise in GMT
DLHRS - number of hours between sunrise and sunset
IGDAY - 0 if local DAYNO and GM DAYNO of sunrise are the same
-1 if GM DAYNO of sunrise is less than local DAYNO
+1 if GM DAYNO of sunrise is greater than local DAYNO.

PROCESS: The subroutine calculates sunrise and the number of hours of daylight for any latitude and longitude in the Northern Hemisphere for any day of the year. Sunrise and sunset will be symmetric with respect to local noon.

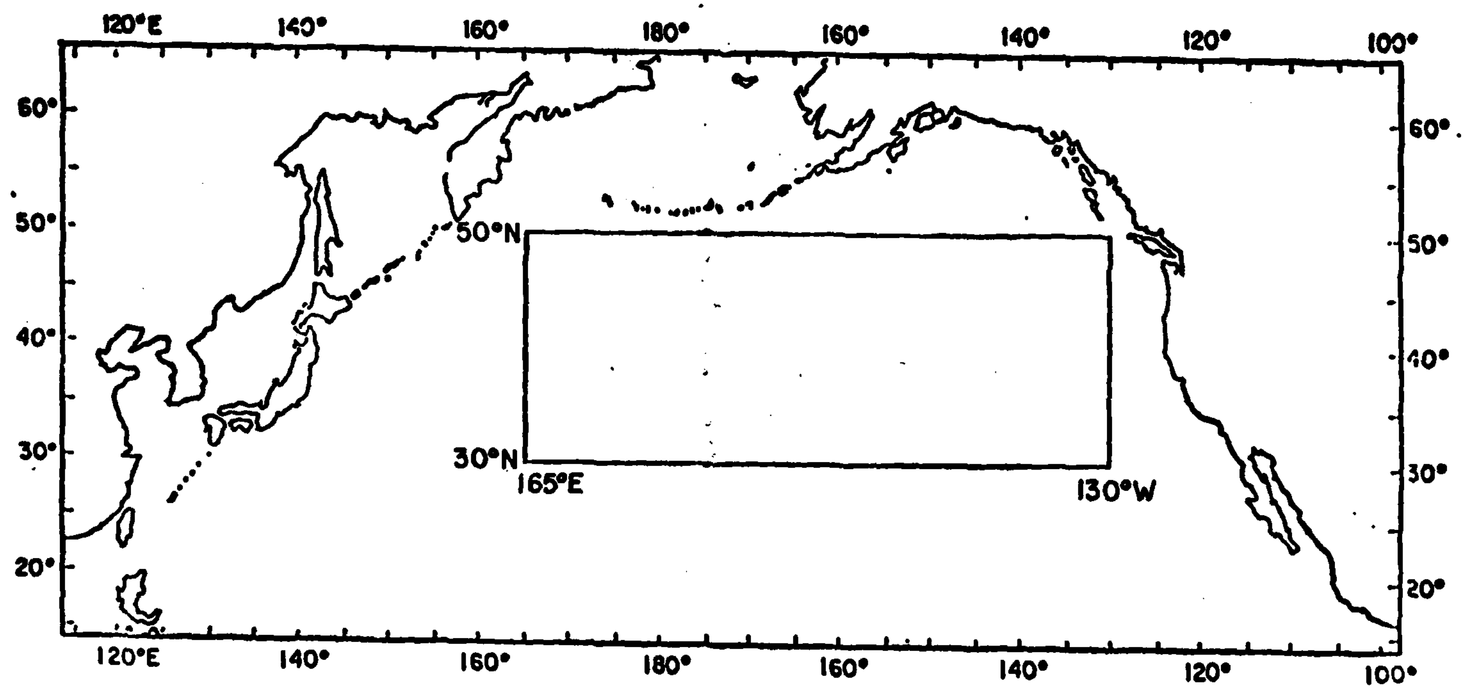

Fig. 1 The Anomaly Dynamic Study (ADS) region (30-50N, 140E-130W).

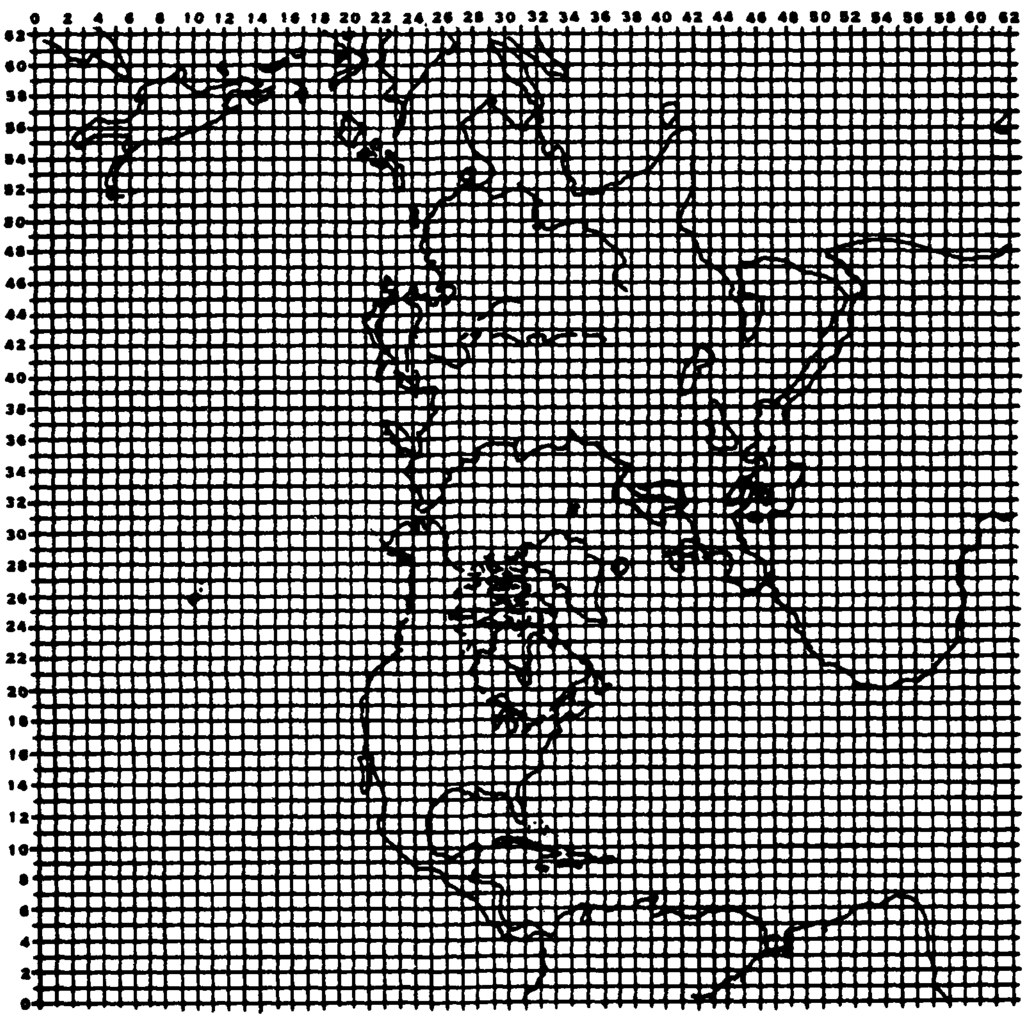

Fig. 2 The 63 x 63 polar stereographic grid for the Northern Hemisphere used by FNWC.

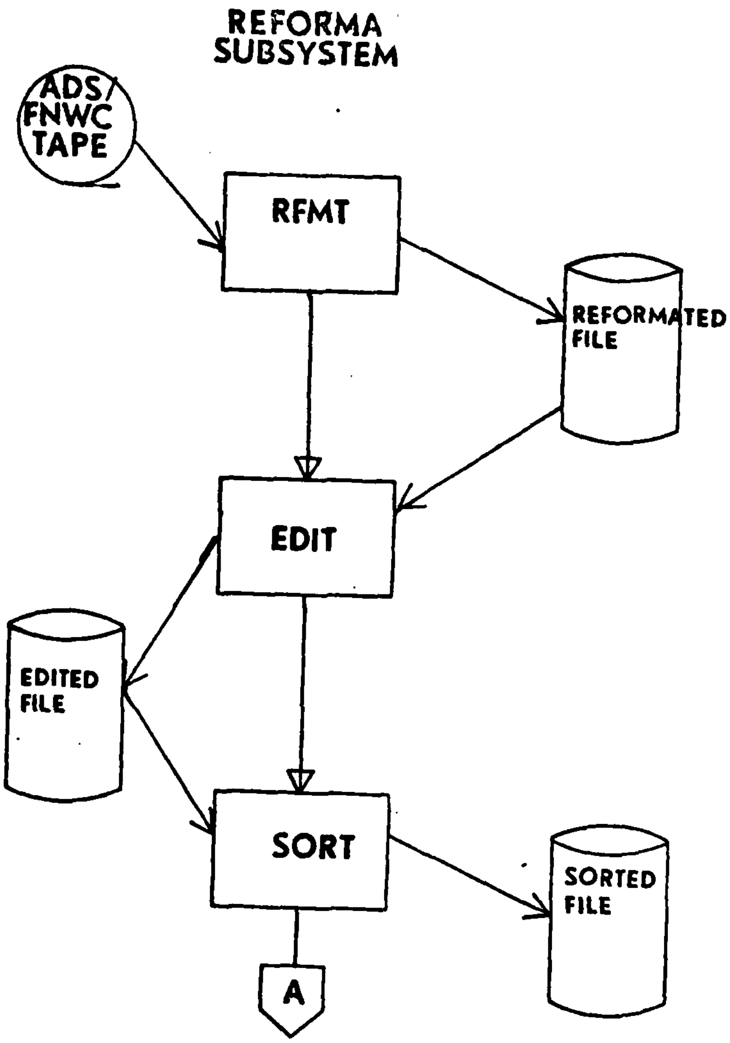

Fig. 3a The REFORMAT subsystem consists of three programs: RFMT, which reformats the data; EDIT, which checks for missing and duplicate fields; and SORT, which resequences the data set.

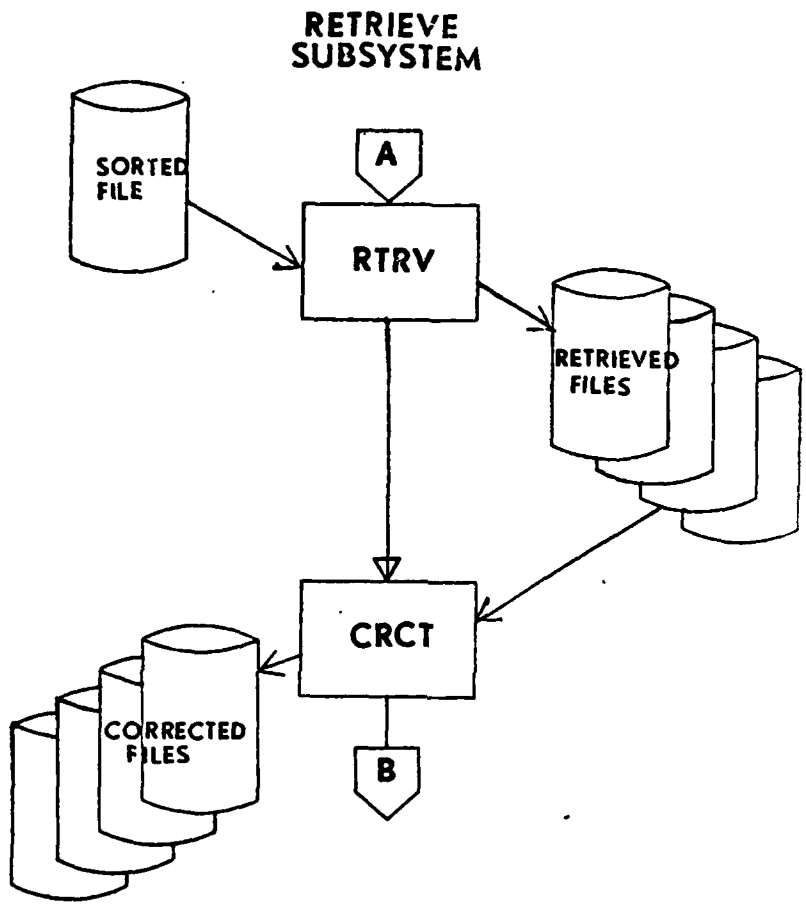

Fig. 3b The RETRIEVE subsystem consists of two programs: RTRV, which retrieves a subset of the complete FNWC or ADS grid; and CRCT, which interpolates values to fill missing fields.

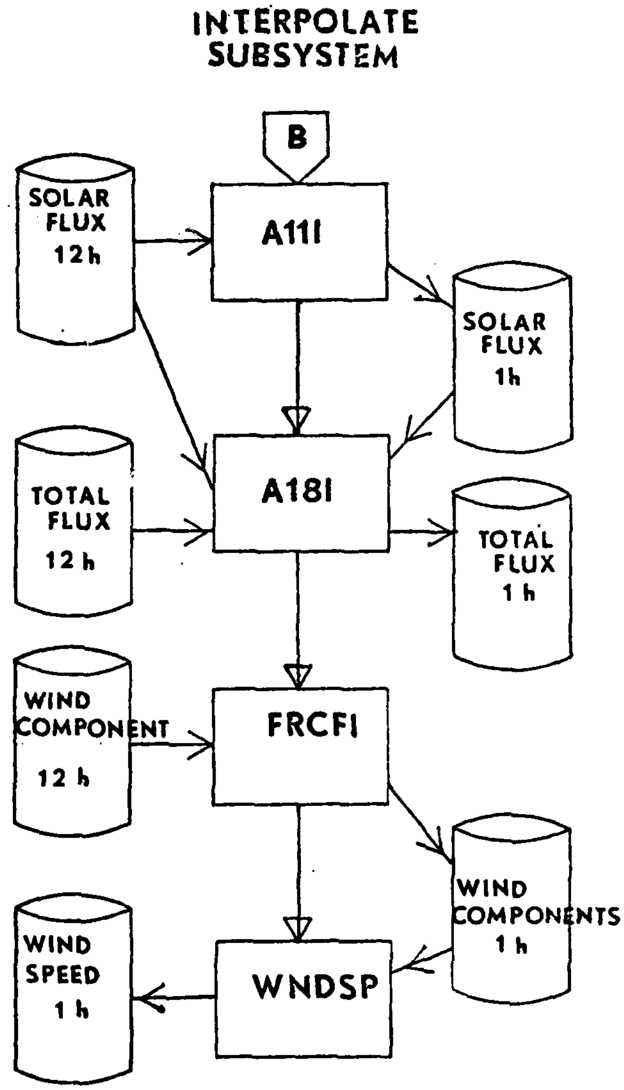

Fig. 3c The INTERPOLATE subsystem consists of four programs: A11I, which interpolates the solar radiation; A18I, which interpolates the total heat flux; FRCFI, which interpolates the wind components; and WNDSP, which computes the wind speed from the vector components.

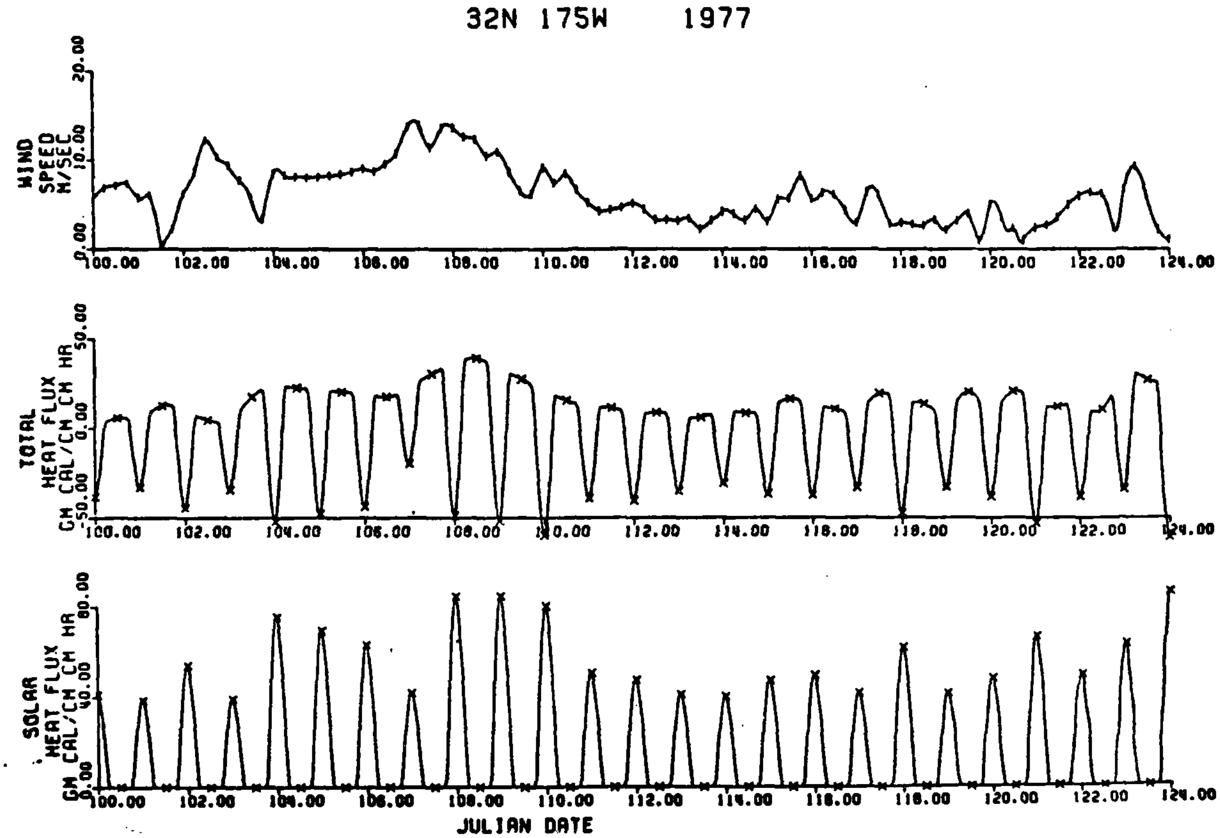

Fig. 4 The interpolated wind speed, total heat flux and solar radiation at the surface for 32N, 175W.

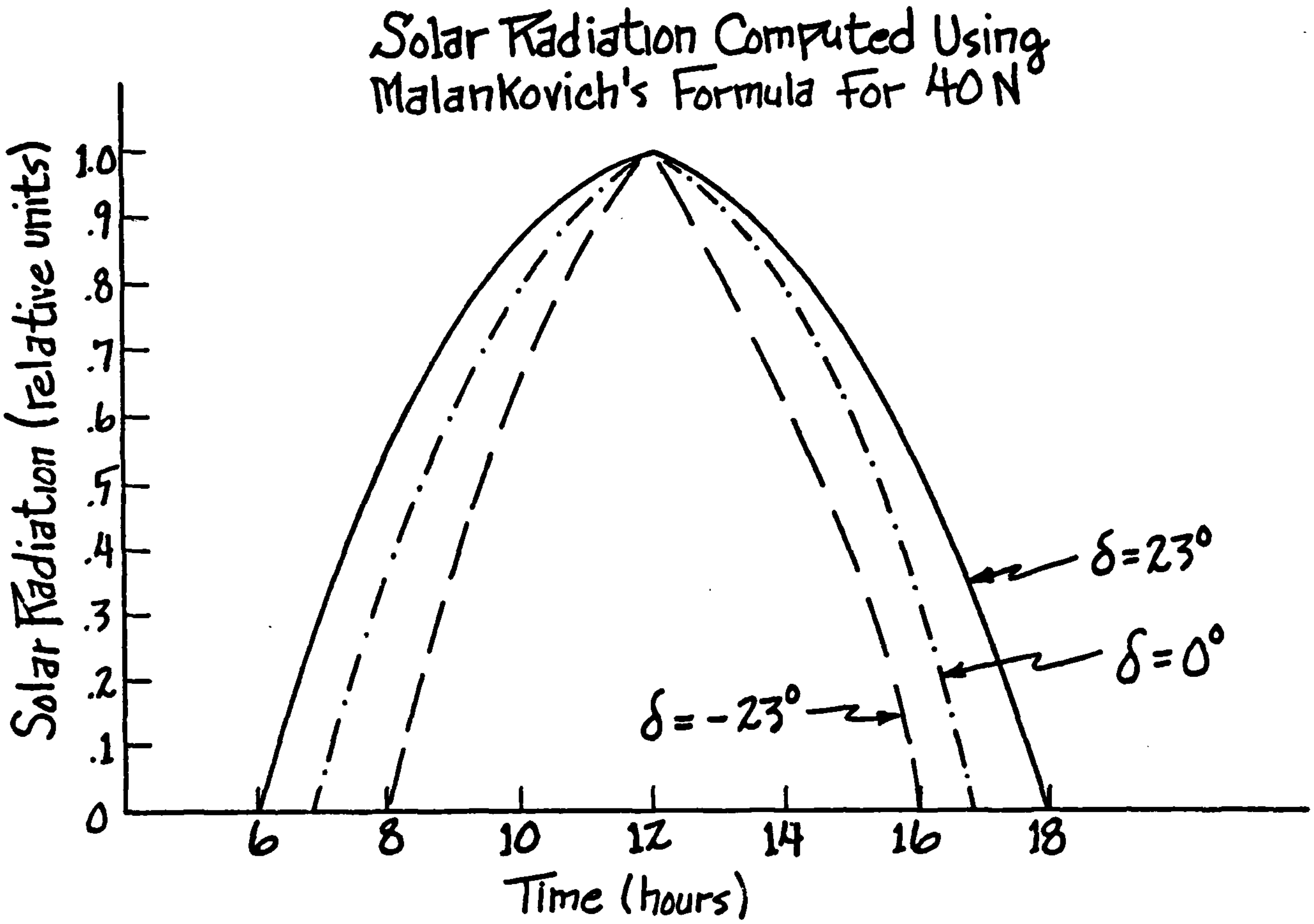

Fig. 5 Values of $\frac{I_i}{I_n}$ computed by Malankovich's formula for 40N, $\delta = 23^\circ, 0^\circ, -23^\circ$.

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